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Interim Performance Specifications for Transducer Modules Used With the Bureau of Mines Intrinsically Safe Mine Monitoring System

Carbon Monoxide, Methane, and Air Velocity

By J. E. Chilton and A. F. Cohen

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATION

TABLES

UNIT OF MEASUREMENT ABBREVIATIONS USED IN THIS REPORT

A/s	ampere per second	mg/m^3	milligram per cubic meter
°C	degree Celsius	µA	microampere
ft	foot	µs	microsecond
ft/min	foot per minute	pct	percent
h	hour	pH	potential of hydrogen
kohm	kilohm	ppm	part per million
mA	milliampere	psi	pound per square inch
m/s	meter per second	s	second
mV	millivolt	V	volt

INTERIM PERFORMANCE SPECIFICATIONS FOR TRANSDUCER MODULES USED WITH THE BUREAU OF MINES INTRINSICALLY SAFE MINE MONITORING SYSTEM

Carbon Monoxide, Methane, and Air Velocity

By J. E. Chilton[1] and A. F. Cohen[2]

ABSTRACT

Interim performance specifications are presented for carbon monoxide, methane, and air velocity transducers used in the Bureau of Mines intrinsically safe mine monitoring system. These specifications give quantitative values or qualitative descriptions of the transducers, including environmental parameters and monitoring system measurement and maintenance requirements as recommended by the Bureau of Mines. Commercially available transducer modules and prototype modules are listed together with selected characteristics.

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INTRODUCTION

The periodic preshift, onshift, and weekly inspections for hazardous conditions in coal mines required by the Code of Federal Regulations (9)[3] include measurement by portable equipment of methane (CH_4) and air velocity at the working face in idle workings, in each air split, and in the main air returns. Other than thermal fire detectors along beltways or machine-mounted methane monitors, no means of continuous monitoring is required. The continuous monitoring of the mine environment with methane, air velocity, and low-level carbon monoxide transducers could significantly improve mine safety and production through the early detection and correction of hazardous conditions (5, 8).

To meet this need, the Bureau has designed and is testing a new type of system called the intrinsically safe mine monitoring system (ISMMS) (5). This system is computer operated for the display and reporting of gas concentrations and air velocity data, and the generation and display of alarms when selected thresholds for measured mine air parameters are exceeded. The system consists of a surface-mounted computer, intrinsically safe power supplies, surface-to-underground mine electrical cables, telemetry systems, and transducer modules[4] for each measured parameter.

The ISMMS was designed so that the monitoring system would continue to operate in mine emergencies. This system measures in-mine environmental conditions even if the mine is closed or sealed and mine power is shut off. Knowledge of the mine environment during an emergency could pinpoint the location of mine fires. This knowledge in turn will help speed mine recovery operations and increase the safety of miners engaged in rescue efforts.

An experimental version of the ISMMS has been installed and is operating at the Safety Research Mine at the Pittsburgh Research Center and in a commercial coal mine in Pennsylvania.

BUREAU OF MINES FIXED-POINT ISMMS

Power for the ISMMS is supplied aboveground by a separate commercial powerline, making it independent of mine power; in addition, the system has a limited-duration battery supply. The system includes a microprocessor controller to record and display data and generate alarms, used in conjunction with intrinsically safe transducer power supplies. The aboveground ISMMS supplies both intrinsically safe power and bidirectional communications to the underground transducers through an approved four-conductor cable. Up to four separate safe trunk circuits, each with an intrinsically safe power supply (ISPS), can be used in the system. Each intrinsically safe power supply provides up to 18 Vdc at 800 mA for operating the transducers.

[3]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

[4]A transducer module as referred to in this report is a device containing a sensor, an amplifier with voltage regulator, and a telemetry system which contains an analog-to-digital converter and a bidirectional data transmitter. A sensor is an electrical device that produces an electrical signal in response to a specific parameter such as CO or CH_4 concentrations, air velocity, or temperature.

LOW-CURRENT TRANSDUCER MODULES FOR THE ISMMS

To accommodate at least 20 parallel-connected transducer modules on one intrinsically safe trunk line for a typical mine subsection, a current of 40 mA per transducer module would be the upper limit. Of the 40 mA, approximately 6 to 15 mA is required for a power regulator, a signal amplifier, and a Conspec accessor.[5,6] Thus, the desired sensors should operate on less than 25 mA.

At least one type of air velocity sensor exists that meets this current requirement. Available methane sensors require at least 60 mA (2); for this reason, the search for lower current methane sensors and/or transducers is part of an ongoing Bureau effort. Commercial carbon monoxide transducers are available that operate at currents as low as 8.5 mA, including the accessor, and thus amply fulfill the minimum current requirement.

INTERIM PERFORMANCE SPECIFICATIONS FOR TRANSDUCER MODULES

Because there is presently no history of in-mine experience with the Bureau's ISMMS monitoring system, the performance specifications presented here are preliminary. Changes in these specifications may be made depending on the results of Bureau research projects on transducer properties and as system performance data are obtained in the mine tests. The initial values recommended for the transducer properties were limited to those obtained by available commercial modules, and these values may not fulfill the ideal intrinsically safe transducer requirements. The ISMMS specifications in this report meet all of the present performance requirements stated for portable monitors in 30 CFR (9).

In addition to performance specifications, approximate costs have been included to aid the design engineer in assessing economic benefits of the ISMMS.

PART 1.--CARBON MONOXIDE

By J. E. Chilton

GENERAL

The intrinsically safe mine monitoring system placed restrictions on the properties of the carbon monoxide transducer modules; these restrictions include low-current operation, low sensor cost, minimum interference from other gases, and stable long-time response. Carbon monoxide detector methods that are used in commercially available sensors operate on four different principles: electrochemical oxidation of CO, absorption of infrared energy, heat of combustion of CO in air on a solid catalyst (Hopcalite), and change of electrical conductivity of solid state materials. The carbon monoxide transducer that best meets the system restrictions uses an electrochemical sensor, and the interim performance specifications have been written specifically with this sensor's characteristics in mind.

[5]A telemetry device that converts the analog output to digital signal for transmission to the computer at the surface.

[6]Reference to specific products does not imply endorsement by the Bureau of Mines.

The interim performance specifications for the carbon monoxide transducer have been divided into four sections: system design requirements, measurement requirements, environmental requirements, and maintenance and other requirements. These interim specifications (table 1) can be met by commercial carbon monoxide sensors with conventional electronic amplifier designs. A diagram of the transducer module is shown in figure 1.

The transducer module for carbon monoxide consists of a CO sensor with a sensitivity of 0.5 μA/ppm CO or greater to minimize the noise contribution. The sensor and amplifier yield a signal of up to 5 V output full scale. On-site (in-mine) calibration of the CO transducer can be performed using a Mine Safety and Health Administration (MSHA) approved digital voltmeter; the calibration will be simplified if the calibration signal is direct reading, e.g., a 50-mV signal for 50 ppm CO gas. The accessor shown in the figure uses 4.5 mA, and the amplifier current needs can be minimized by the use of newer solid state amplifier circuitry where possible. The current limits have been set to allow a maximum number of transducers on a single line. Some gas transducer designs have incorporated light-emitting diodes (LED's) for zero and span set points. The LED's need 5 to 7 mA additional current to operate; if the mine atmosphere is normally 0.0 ppm CO, the zero signal LED will remain on, drawing extra current, which may additionally limit the total number of transducers used per line.

A displaced or live zero is recommended for use, e.g., if a zero gas signal value of 0.5 V is used then a 0.0 V-output would indicate a transducer failure mode. The range of 0 to 50 ppm was recommended for the CO transducers so that CO could be used for early detection of fires.

Other concentration ranges, 0 to 500 ppm CO, may be considered if monitoring for health or toxic gas environment is contemplated. The Mine Safety and Health Administration (MSHA) requirement for toxic levels of CO is 50 ppm CO for a time-weighted average miner exposure for an 8-h shift, with short-term exposure limits of 400 ppm CO. The overall accuracy requirement was written to include response variations due to precision, linearity over range, calibration error, drift over 1-month duration, and temperature changes of 10° C for a CO transducer. The 2-min response time for the CO transducer is necessary because transport of CO to the sensor occurs by convection and diffusion alone, and these transport processes are slow. Pumped sampler sensors have faster response time, but they have not been considered because of the excessive current use of the electric pump motors. A faster response will reduce the time required to calibrate the transducer.

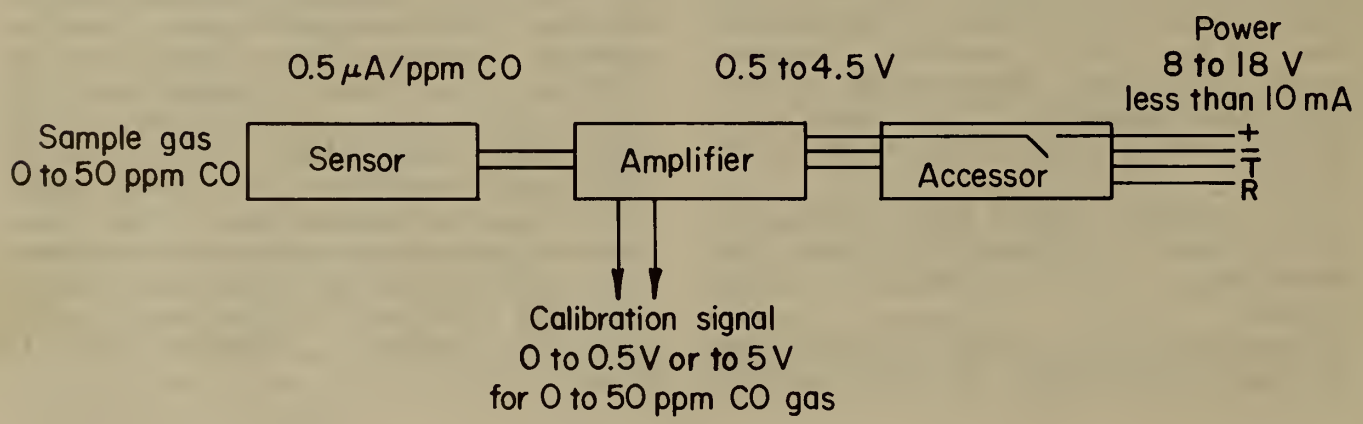

FIGURE 1. - Carbon monoxide transducer module.

TABLE 1. - Interim performance specifications for carbon monoxide transducer modules

(For Bureau of Mines remote underground continuous fixed-point intrinsically safe coal mine monitoring system)

Characteristic	Interim performance specifications	Rationale
	1.0 SYSTEM DESIGN REQUIREMENTS	
1.1 Carbon monoxide transducer module input current, continuous.	Current less than 10 mA.....	The BOM ISMMS power supply has a current limit of 800 mA per trunkline. The total number of CO-transducer modules that can be attached to 1 trunk line is determined by the individual transducer currents.
1.2 Transducer module current, surge upon power application.	Current increase shall be linear with resistive character without overshoot or surge.	The power supply will turn off if load exceeds 800 mA or if sudden changes in voltage or load current are detected.
1.3 Transducer module input voltage.	Normal operating voltage is 8 to 18 Vdc and must withstand intrinsic safety tests at 26 Vdc.	The transducer module will be powered by the Bureau-designed power supply which operates at 18 Vdc and meets intrinsically safe operation requirements (7). The voltage at a transducer depends on its distance along the cable and total number of transducers on a trunk line.
1.4 Electrical system and transducer module recovery time following loss of power to monitoring system.	Response will meet accuracy standards within 20 min.	All transducers exhibit a stabilization or warmup time after power turn on. Electrochemical-based CO transducers have been found to produce a full-scale output followed by a slow recovery to the normal response upon reapplication of power following a power interrupt of several minutes. During recovery the transducer is not responding accurately, and its output must be ignored. The recovery period should be kept short to minimize the loss of the monitoring ability of the system.
1.5 Output signal current.	At least 1 mA at full output voltage, 5 V.	The accessor input impedance is 5 kohm.
1.6 Output signal voltage.	0.5 to 4.5 V for zero to full-scale CO concentration (50 ppm). 0 V indicates malfunctioning or unpowered transducer.	The accessor maximum input voltage is 5 V. Live zero (0.5 V for 0 ppm CO) is necessary for detection of transducer malfunction.
1.7 Output signal behavior.	A monotonic signal with voltage value increasing for an increase of CO concentration.	A single-valued signal is necessary for unambiguous interpretation of data.
	2.0 MEASUREMENT REQUIREMENTS	
2.1 CO measurement range.	The range shall be 0 to 50 ppm CO or higher.	The range is limited to low values of concentration to conform with MSHA early fire warning protocol (6), which specifies that alarms are to be set for 5 ppm and 10 ppm above normal CO background. Accessor resolution is 1 in 256 for 5 V. Full-scale (4.5 V and 50 ppm) gives 0.2 ppm digital resolution.

TABLE 1. - Interim performance specifications for carbon monoxide transducer modules--Continued

Characteristic	Interim performance specifications	Rationale
	2.0 MEASUREMENT REQUIREMENTS--Continued	
2.2 Overall accuracy....	The response to CO concentration within the transducer module range for a 1-month period shall have an inaccuracy including bias and precision of less than ±2 ppm CO at a sample concentration of 5 ppm CO or less and ±4 ppm CO at a sample concentration of 25 ppm CO.	Accuracy shall include response variation terms from calibration error, precision, drift, and temperature changes (1). See rationale of 2.1. False alarms from response inaccuracy must be minimized.
2.3 Response-rise time..	Upon applying a step increase in CO concentration to a transducer module, the time interval from initial response to a response value that is 90 pct of final value shall be less than 2 min.	CO transducer modules have response times of 2 min or less. Fast transducer response is recommended for mines with CO sources such as diesel haulage to discriminate between short- and long-term CO concentration changes to aid fire detection. Fast response will decrease the time required to calibrate the transducers.
2.4 Response-recovery time.	Upon applying a step decrease in CO concentration to a transducer module, the time interval from initial response to a response value 10 pct greater than the final value shall be less than 2 min.	See rationale 2.3.
2.5 Response upon application of power after power interrupt-recovery time.	Same as 1.4. Response shall meet accuracy specification in less than 20 min from application of power.	Same as rationale for 1.4.
2.6 Stability-zero, response variation with time in pure air.	The response drift in pure air shall be less than ±1 ppm CO per month.	Response variation with time for unadjusted continuous operation with no CO present should be much less than MSHA-recommended alert level for monthly calibration schedule (6).
2.7 Stability-span, response variation in sensitivity with time.	The response drift (change in sensitivity) with a CO challenge gas shall be ±10 pct of the gas concentration per month or less.	The response variation in transducer output from drift in presence of CO should be less than total accuracy requirement, and calibration should be needed no more frequently than once per month to maintain accuracy.
2.8 Calibration:		
2.8.1 Procedure.....	A standard calibration procedure must be specified by transducer manufacturer for in-mine calibration.	Uniform procedure for calibration shall be used to maintain transducer accuracy for intercomparison of measured values within mine.
2.8.2 Calibration--test gas.	A calibration kit shall contain necessary parts for test and reset (if necessary) of zero and span setting at the mine by means of the measured transducer responses. The test gases shall have an analysis accuracy of ±1 pct or less of stated reading.	Accuracy of transducer must be checked and transducer reset on-site using standard calibration gases.

TABLE 1. - Interim performance specifications for carbon monoxide transducer modules--Continued

Characteristic	Interim performance specifications	Rationale
2.0 MEASUREMENT REQUIREMENTS--Continued		
2.8.3 Calibration duration.	Time for calibration and reset shall be less than 10 min.	Minimize labor and time spent on calibration operations and off-line time for transducers. Calibration time is determined by transducer response time to zero and span gases, plus the attachment of fixtures, handling gas bottles, and adjustments.
2.8.4 Calibration period.	The period between calibrations shall be no more than 30 days.	See rationale 2.8.3.
2.8.5 Calibration accuracy.	Response must be set to within overall accuracy by transducer calibration procedure.	Minimize bias between responses obtained with calibration kit and responses to equal concentrations of CO in mine.
3.0 ENVIRONMENTAL REQUIREMENTS		
3.1 Intrinsic safety....	Transducer module must be designed and fabricated to meet requirements of MSHA Approval and Certification Center for operations in methane-air mixtures, 30 CFR 18, Electric Mine Accessories (9).	Mine monitoring system must continue to operate in returns and throughout the mine in emergencies.
3.2 Operating temperature.	The transducer shall operate from 4° to 40° C within accuracy requirements.	Operational temperature limits are set by freezing point of sensor electrolyte and range of mine temperatures.
3.3 Storage temperature.	The transducer shall tolerate storage from -40° to 50° C temperatures.	Surface storage and transportation of transducer module or parts may be in uncontrolled environments.
3.4 Operating relative humidity.	Transducer shall meet accuracy requirements in atmospheres from 10 to 95 pct relative humidity.	Continuous operation in wet or dry mines will occur and must not cause failure of transducer electronic circuits or sensor or affect the accuracy of measurement.
3.5 Atmospheric pressure.	Transducer module operation will meet accuracy requirements with pressure variations encountered in mines.	Ventilation and barometric pressure changes affect mine atmospheric pressures and may change CO transducer response.
3.6 Corrosive environment.	Operation demonstrated after acid spray test (salt spray, if justified) pH 3.1 to 3.3, 120 h.	Continuous mine operation may result in contact with acid gases, dust, and liquids with air >95 pct relative humidity (3).
3.7 Shock test.....	Survive drop test at 36-in height onto wooden floor.	Survive transport in mines; 30 CFR 22.7 (4, 9).
3.8 Electromagnetic interference (EMI).	Survive conductive radiative susceptibility tests at mine radio communication frequencies and random power transients.	Transducer interaction with EMI such as that from power transients or mine communications shall not cause false alarms.
3.9 Sand, dust, and airflow.	Transducer shall operate in sand or dust to 10 mg/m^3 and air velocity to 20,000 ft/min.	Transducer module operation and accuracy shall be minimumly affected by airflow or particulate deposition (3).

TABLE 1. - Interim performance specifications for carbon monoxide transducer modules--Continued

Characteristic	Interim performance specifications	Rationale
	3.0 ENVIRONMENTAL REQUIREMENTS--Continued	
3.10 Physical properties:		
Size.....	Minimum size.	Safe and easy transportation and set up by miner; design for minimum dust and water drop interaction in upright position.
Shape.....	Have no sharp projections or corners.	
Weight.....	Make minimum weight.	
Mounting.....	Mount in designated position.	
3.11 Specificity to carbon monoxide.	Effect on transducer response by other gases in mines shall be minimized.	Gases such as methane or hydrogen sulfide naturally occurring in mines, nitrogen oxides from explosive fumes or diesel exhaust, or hydrogen from battery charge stations shall cause minimum transducer response.
	4.0 MAINTENANCE AND OTHER REQUIREMENTS	
4.1 Field inspection and maintenance.	Minimum or no more frequently than calibration.	Minimize maintenance costs (labor).
4.2 Transducer parts replacement.	Module replacement in mine; sensor life 1 year minimum.	Minimize transducer out-of-service time.
4.3 Documentation.....	An operational and maintenance manual shall be supplied containing, as a minimum, the following items: Manufacturer's name, location, telephone. Unpacking and assembly procedures. Warranty information. Use restrictions. Intrinsic safety statements, agency, permit number, date. Principle of operation and theory. Operating instructions and detailed figures. Performance specifications. Calibration procedures, kit information, gas cylinder replacement. Gas interference table. Maintenance instructions, circuit diagrams, troubleshooting steps, voltage check points. Parts list, production number of part, source, replacement cost.	Adequate documentation is necessary for optimum transducer use and upkeep.

TABLE 2. - Manufacturers and properties of commercially available CO transducers (Manufacturer's specifications)

Manufacturer and model	Input voltage, Vdc	Input current, mA[1]	Output voltage, Vdc	Range, ppm CO	Drift	Accuracy	Estimated cost 1983
Dynamation, series 4000.	5 -35	3	0.0-0.5	0-500	ND	ND	$500
Energetics Science, model 5001.	8 -28	[2]17 [3]24	0 -1	0- 50 or 0-500	ND	ND	$500
General Electric, model 15ECS6C01.	7.2-30	4	.5-4.5	0- 50	(Zero) ±1 ppm/mo	+1 ppm at 10 ppm CO	ND
Interscan, model 114-D.	±3 or +15	2	0 - .01 or 0 - .20	0- 50 or 0-250	ND	±2 pct of reading	$400
Mine Safety Appliances.	11 -28	7.3	.5-4.5	0- 50	ND	ND	ND

ND No data.
[1]Current for transducer without accessor.
[2]Current without ALARM function.
[3]With calibration LED on.

The requirement of specific response to carbon monoxide may be relaxed if the CO transducer is used as an early fire-warning system. Fires in coal will produce other oxidizable species such as nitrogen oxides, and these gases, in addition to CO, will give an increased transducer response. If a mine has alternate sources of these gases, such as nitrogen oxides and carbon monoxide from diesel exhaust products, then a sensor specific to CO may be necessary.

COMMERCIALLY AVAILABLE CARBON MONOXIDE TRANSDUCER MODULES

The CO transducer modules are commercially available from a number of manufacturers as either prototype devices or as a fully manufactured and MSHA-certified product. These manufacturers and selected CO transducer module properties are summarized in table 2. The properties listed include input voltage and current, output voltage, range and drift, accuracy, and cost when the data were given. Although there are many more manufacturers of CO sensors and of portable CO monitoring equipment, only those manufacturers known to produce transducer modules have been included in this list.

Performance tests of some of the CO transducer modules have been conducted at the Bureau. These modules include prototype units from General Electric (model 15ECS6C01), Energetics Science (model 5001), and Mine Safety Appliances. The CO performance specifications can, in general, be met by these transducer modules. Five of the General Electric CO transducers have been installed in a cooperating coal mine in Pennsylvania and for the Past 11 months have received zero drift and periodic calibration check tests.

PART 2.--METHANE

By A. F. Cohen

GENERAL

The methane transducer module must be compatible with practical monitoring system needs of maximizing the number of modules per trunk line. The ideal ISMMS requirement of 40 mA for the transducer module (based on at least 20 transducers on a trunk line) cannot be realized with existing methane sensors; accordingly an interim operating current methane transducer specification of 80 mA is given in table 3. This table lists methane transducer characteristics, interim performance specifications, and rationale.

TABLE 3. - Interim performance specifications for methane transducer modules

(For Bureau of Mines remote underground continuous fixed-point intrinsically safe coal mine monitoring system)

Transducer module characteristic	Interim performance specifications	Rationale
	1.0 SYSTEM DESIGN REQUIREMENTS	
1.1 Methane transducer module input current (continuous).	Current less than 80 mA (1982 design limits).	Bureau of Mines ISMMS power supply has a current limit of 800 mA per trunk line. The total number of methane transducer modules on a trunk line is equal to the sum of the individual transducer currents.
1.2 Transducer module input current (surge upon initial power application).	Current increase shall be linear with time; circuit should be resistive looking (ohmic) and capable of accepting a 500-μs turn-on without overshoot or surges in current.	Power supply current limiter will trip if current spike greater than 1 A/s is detected.
1.3 Transducer module input voltage.	Normal operating voltage range is 8 to 18 Vdc. Circuit must be capable of operating at 26 Vdc for intrinsic safety testing.	The transducer module will be powered by the Bureau of Mines ISPS, which has a dynamic range of 8 to 18 Vdc.
1.4 Electrical system and transducer module recovery time following loss of power to monitoring system.	Response will meet accuracy requirements within 20 min. Also, same characteristic as (1.2) upon recovery.	30 CFR 75.307 (9). Limit time transducer module is out of service (to correspond to maximum time of 20 min allowed between readings at the face in present CFR regulation for handheld instruments).
1.5 Transducer output current.	0 to 1 mA.....	Input impedance of accessor board is 5,000 ohms.
1.6 Transducer output voltage.	0- to 5-Vdc range of detection; voltage to accessor should have a linear range from 0.25 to 5.0 V with dynamic range being 0.5 to 4.5 V and output being 0.5 V at 0 pct CH_4 and 4.5 V at 5 pct CH_4. 0 V indicates malfunctioning or unpowered transducer.	Accessor input voltage requires 5 V for maximum resolution with displaced zero.
1.7 Transducer output signal.	Linear signal proportional to methane concentration in range of detection.	Linear requirement convenient for simple microcomputer usage.

TABLE 3. - Interim performance specifications for methane transducer modules--Continued

Transducer module characteristic	Interim performance specifications	Rationale
2.0 MEASUREMENT REQUIREMENTS		
2.1 Range.....	0 to 5 pct methane in air.....	30 CFR 22.7 (9).
2.2 Accuracy over a 30-day period in-mine, including factors that can affect accuracy; i.e., zero drift per month, span drift per month; poisoning by silicones or other vapors, zero shift and/or sensitivity changes due to momentary exposures of 1.5 pct CH_4, or exposures to atmospheres with velocities of 0 to 1,700 ft/min.	Allowable variations in scale reading over 1 month are-- Methane content, pct / Minimum indication, pct / Maximum indication, pct 0.25 / 0.10 / 0.40 .50 / .35 / .65 1.00 / .80 / 1.20 2.00 / 1.80 / 2.20 3.00 / 2.70 / 3.30 4.00 / 3.70 / 4.30 Accuracy must be maintained when exposed to range of air velocities found in U.S. coal mines (0 to 1,700 ft/min).	(a) Accuracy of portable methane detectors and (b) sensor is calibrated and zeroed on monthly schedule. Calibration once per month. Measured CH_4 concentrations (due to all factors) must not differ from true values (for 1 month operating time) by more than allowed in table given here. Typical range of air velocities in U.S. coal mines extends from 0 to 1,700 ft/min. In most mines it is 200 to 600 ft/min.
2.3 Speed of response.....	Less than 60 s to reach 90 pct of final reading (for a step change in concentration).	Achievable by transducer module manufacturers.
2.4 Calibration:		
2.4.1 Procedure.....	A standard procedure should be specified by the manufacturer.	A uniform procedure is available to maintain accuracy.
2.4.2 Calibration kit.	A calibration kit shall be available.	
2.4.3 Ease of calibration.	Calibration requires <15 min by a qualified person.	Downtime of system minimized. 30 CFR 75.307 (9). "Monitor for Methane at 20-Min Intervals During the Operation of Electrically Operated Equipment" requirement.
2.5 Specificity.....	In presence of other combustible gases, output signal should be in fail-safe direction; sensor should not be unduly affected by CO, CO_2, or water vapor.	Coal mines may contain other combustible gases (hydrogen, ethane). Sensor should be made as specific as possible for methane. In presence of hydrogen or ethane, the net signal will be greater than for methane alone (in fail-safe direction).
3.0 ENVIRONMENTAL REQUIREMENTS		
3.1 Intrinsic safety.....	Must meet MSHA approval for intrinsic safety.	30 CFR 27 (9).
3.2 Ambient storage temperatures.	Must be operational between -20° and +40° C within accuracy requirements; must survive storage temperatures between -40° C and +50° C.	Representative underground temperatures in U.S. coal mines (3).
3.3 Relative humidity.....	Operational at 30 to 100 pct relative humidity (coal mines).	Dayton T. Brown, Inc. (3).

TABLE 3. - Interim performance specifications for methane transducer modules--Continued

Transducer module characteristic	Interim performance specifications	Rationale
	3.0 ENVIRONMENTAL REQUIREMENTS--Continued	
3.4 Atmospheric pressure (equivalent).	Calibratable and operational between 9.7 and 19.7 psi. Low pressure equivalent to 10,000 ft above sea level. High pressure equivalent to 10,000 ft below sea level.	Dayton T. Brown, Inc. (3).
3.5 Corrosive environment.	Functional after acidified salt spray test (5 pct salt; pH 3.1 to 3.3).	Do.
3.6 Shock.....	Must survive drop test at maximum height (36 in) onto a wooden floor.	Do.
3.7 Electromagnetic interference.	Must survive all conducted and radiated susceptibility tests using National Bureau of Standards spectral densities without transducer degradation.	Do.
3.8 Sand and dust.....	Must be operational at 10 mg/m^3 dust up to 1,750 ft/min (air cleaner test dust classified from Arizona Road Dust).	30 CFR 27.22 (9).
3.9 Size, shape, and weight.	Minimum weight and size consistent with sufficient ruggedness to endure mine environment.	Physical damage in close quarters possible. To insure system reliability, easy installation of transducer module, and easy maintenance, minimum size and weight are required.
3.10 Design and restrictions.	Must be able to be hung or supported in mine in appropriate places to monitor adequately. Must survive normal mine operations.	30 CFR 75.308 - 75.310 (9).
	4.0 MAINTENANCE AND OTHER REQUIREMENTS	
4.1 Maintenance:		
(a) Inspection.....	Performance inspection no more frequent than once per week unless sensor is clearly inoperative (fault condition). Inspection: Check span drift and accuracy at 2.5 pct CH_4; check drift at zero gas. If total drift (zero drift and span drift) out of specification (see accuracy), recalibrate. Labor and material for inspection less than 1 pct of unit transducer cost.	
(b) Parts replacement.	Less than 1/2 h by qualified maintenance personnel.	Cost consideration.
(c) Parts availability	Spare parts must be available.	
4.2 Sensor life.....	>1 year.	Do.
4.3 Documentation, installation, and user's manual.	Manufacturer should provide clear and complete installation and user's manual and troubleshooter guide, including detailed circuit diagrams and calibration procedure for mine use.	Accuracy requirement and to insure system reliability.

To insure the intrinsic safety of the system, the transducer modules must be intrinsically safe. Response time must be sufficiently short (<60 s) and recovery time of the transducer under loss of power must be sufficiently short (<20 min) for continuous monitoring integrity. Accuracy must be maintained between monthly calibrations. Finally, the transducer module must survive the coal mine environment and meet practical tests such as physical size and weight.

Section 1.0 of table 3 refers to systems requirements specific to the ISMMS for continuous fixed point operation. Section 2.0 concerns methane measurement. Individual characteristics include items related to accuracy of methane detectors as stipulated in 30 CFR 22.7 (9). If we assume a monthly calibration schedule, the maximum methane transducer total drift and effects on transducer output such as poisoning, lack of specificity, high-concentration methane bursts, and air velocity level, taken together, must be such that the permitted deviation in accuracy (30 CFR 22) is not exceeded over a monthly operating period. Response time, maintenance, and range of detection are included in the table. For the present, the transducer range is limited to 0- to 5-pct CH_4 concentrations.

The intrinsic safety specification (3.1) is used to satisfy the permissibility requirement (30 CFR 27) (9).

Items 3.2 to 3.8 are environmental factors, such as temperature and pressure, which the transducer must be able to endure.

COMMERCIALLY AVAILABLE METHANE TRANSDUCER MODULES

As has been stated, the components of the first iteration of the ISMMS other than the intrinsically safe power supply were to be as nearly as possible off-the-shelf (commercially available) items. Table 4 lists commercially available methane transducer modules and characteristics essential for use in the ISMMS. In addition to current and voltage characteristics, range of detection and cost, if available, are given.

TABLE 4. - Manufacturers and properties of commercially available methane transducers

Manufacturer and model	Input voltage, Vdc	Input current, mA	Output voltage, Vdc	Range of detection, pct CH_4	Cost (1982)
J&S Sieger, Ltd. (England) BM1 detector head (00747-A-0001) with English Electric Valve Ltd. sensor VQZ.	10.7 -16.0 [1]2.0	ND [1]180	0.4-2.0	0.0-3.0	ND
MSA mine surveillance methane-sensing assembly (built for BOM) with MSA series 510 sensor 463163.	13.0 -15.0 [1]1.88	700 [1]400	ND	.0-5.0	Approx. $800 per channel
J-Tec Associates model VM101 with English Electric Valve Ltd. sensor VQ1.	10.5 -18.0 [1]2.2	140 [1]375	.0-5.0	.0-5.0	<$1,000
J-Tec Associates model VM101B with Scott Aviation sensor:	12.0 -21.0	75	.5-5.0	.0-5.0	$950
Standard, 40008560.....	[1]5.5	[1]60			
Prototype, 40010161.....	[1]5.5	[1]60			
Texas Analytical Controls Inc. combustible gas sensor assembly (part 200A) with Scott Aviation standard sensor 40008560.	7.0 - 8.0 [1]5.5	75-80 [1]60	.2-3.0	.0-3.0	$300

Nd No data. [1]Sensor only.

It should be noted that manufacturers of the many available portable or fixed instruments that measure methane concentration are potential providers of transducers. However, instrument manufacturers who do not provide CH_4 transducers have not been listed here.

Two transducer modules using the 60-mA Scott Aviation sensor are available (table 4, last two items). The last manufacturer has only recently been producing this module, which has not yet been tested, and laboratory tests to date at the Bureau have been limited to model VM101B methane transducer modules by J-Tec Associates. Results for the sensor in this module (particularly Scott sensor part No. 40010161) appear good (2) for ISMMS use. The commercially available methane transducer module (J-Tec No. VM101B using sensor No. 40010161) has a response time of <30 s and a 0- to 5-pct CH_4 range and is expected to satisfy the accuracy requirement between monthly calibrations. An initial sensor burn-in period (for the sensor) may be required.

Thorough laboratory testing of many table 3 characteristics using six J-Tec methane transducer modules with the standard 40008560 sensor is in progress at the Pittsburgh Research Center. J-Tec VM101B modules with the standard sensors have been installed at the Bruceton Safety Research Coal Mine for in-mine tests, as well as at a cooperating coal mine in Pennsylvania.

Further research is indicated to reduce the transducer current required by at least a factor of to meet perceived methane-sensing requirements for underground coal mines using ISMMS.

PART 3.--AIR VELOCITY

By A. F. Cohen

GENERAL

The ideal ISMMS requirements for air velocity transducers would include capability of generating an output at very low velocities (<10 ft/min) and yielding information on directions of flow in case of airflow reversal. To date, no one air velocity transducer meets all requirements. Therefore, the interim velocity transducer specifications do not include direction of the air velocity nor measurement of velocities below 50 ft/min.

Table 5 lists transducer characteristics, interim performance specifications, and rationale. Section 1.0 relates to specifics of the ISMMS mine monitoring system. The low current (item 1.1) and 18-Vdc limitation (item 1.3) are associated with the Bureau's ISPS design characteristics; item 1.2 relates to the presence of a current limiter.

Section 2.0 of table 5 is concerned with air velocity measurement and with environmental and operational requirements necessary to obtain maximum information and operating life.

Transducer characteristics include items related to accuracy (item 2.2). Assuming a monthly calibration schedule, the total of factors that may affect the air velocity transducer accuracy such as total drift, temperature, or pressure change must not exceed the allowed deviation of air velocity over a monthly in-mine operating period.

Table 5, section 2.0, includes response times appropriate to real mine conditions and calibration of transducers. For the present, consideration is limited to coal mines, hence, mostly to 200- to 600-ft/min air velocities. The intrinsic safety specification is used to satisfy the permissibility requirement (30 CFR 27). Also included are environmental factors such as temperature, pressure, dust, and humidity, which the transducer must be able to endure. Other items for practical consideration are size, weight, design restrictions, cost, and lifetime.

TABLE 5. - Interim performance specifications for air velocity transducer modules

(For Bureau of Mines remote underground continuous fixed-point intrinsically safe coal mine monitoring system)

Transducer module characteristic	Interim performance specifications	Rationale
	1.0 SYSTEM DESIGN REQUIREMENTS	
1.1 Air velocity module input current (continuous).	Current less than 40 mA.....	Bureau of Mines ISMMS power supply has current limit of 800 mA per trunk line. Total number of air velocity transducer modules on each trunk line is equal to the sum of the individual transducer currents.
1.2 Transducer module input current (surge upon initial power application).	Current increase should be linear with time; circuit should be resistive looking (ohmic) and capable of accepting 500-μs turn-on without overshoot or surges in current.	Power supply current limiter will trip if current spike greater than 1 A/s is detected.
1.3 Transducer module input voltage.	Normal operating voltage range is 8 to 18 Vdc. Circuit must be capable of operating at 26 Vdc for intrinsic safety testing.	Transducer module will be powered by Bureau power supply, which has dynamic range of 8 to 18 Vdc.
1.4 Electrical system and transducer module recovery time following loss of power to monitoring system.	Response will meet accuracy requirements within 20 min. Also, same characteristic as (1.2) upon recovery.	30 CFR 75.307 (9). Limit time transducer module is out of service (to correspond to maximum time of 20 min allowed between readings at the face in present CFR regulations for handheld instruments).
1.5 Transducer output current.	0 to 1 mA.....	Input impedance of accessor board is 5,000 ohms.
1.6 Transducer output voltage.	0- to 5.0-Vdc active range of detection; 0.5 to 4.5 V corresponds to 0- to 1,000 or 0- to 3,000 ft/min velocity transducer. Voltage to accessor should have linear range of 0.5 to 5.0 V with dynamic range of 0.5 to 4.5 V, output being 0.5 V at zero velocity and 4.5 V at maximum velocity.	Accessor input voltage requires 5 V for maximum resolution with displaced zero.
1.7 Transducer output signal.	Linear signal proportional to air velocity in range of detection.	Linear requirement convenient for simple microcomputer usage.
	2.0 MEASUREMENT REQUIREMENTS	
2.1 Range.....	2 models should be available: 50 to 1,000 ft/min (0.25 to 5.0 m/s) (most applications) and 50 to 3,000 ft/min (0.25 to 15.0 m/s). (Transducer must respond to velocity of 50 ft/min at low end.)	30 CFR 75.301-4 (9). Minimum mean entry air velocity must be 60 ft/min. Typical range of air velocities in U.S. coal mines is 0 to 1,700 ft/min. In most coal mines it is 200 to 600 ft/min.

TABLE 5. - Interim performance specifications for air velocity transducer modules--Continued

Transducer module characteristic	Interim performance specifications	Rationale
	2.0 MEASUREMENT REQUIREMENTS--Continued	
2.2 Accuracy (over a 30-day period) of air velocity in-mine including those factors that can affect accuracy such as zero drift, span drift, temperature, and pressure.	±10 pct of reading >150 ft/min....	Sensor calibrated and zeroed on monthly schedule.
	±20 pct of reading in range 50 to 130 ft/min.	30 CFR 75.301-4 (9). Minimum mean entry velocity at face = 60 ft/min.
		According to ventilation engineers, ±10 pct of reading is desirable accuracy for 150- to 1,000 ft/min air velocity.
		Typical range of air velocities in U.S. coal mines extends from 0 to 1,700 ft/min. In most coal mines it is 200 to 600 ft/min.
	Absolute accuracy of device must be within ±10 pct of true value after installation and in-mine calibration at 150 to 1,000 ft/min ±20 pct of true value at 50 to 140 ft/min.	Factors to be considered for in-mine calibrations are being determined.
2.3 Speed of response.....	<120 s to reach 90 pct of final reading (for a step change in velocity).	
2.4 Calibration:		
2.4.1 Procedure.....	A standard procedure should be specified by the manufacturer.	A uniform procedure is available to maintain transducer accuracy for intercomparison of measured values with mines.
2.4.2 Calibration kit..	A calibration kit or equivalent should be available for in-mine calibration, for zero reset if required, and for cleaning transducer if required (dust).	Accuracy of transducer to be checked without system upset or alarm.
2.4.3 Ease of calibration and calibration schedule.	Calibration requires less than 15 min by a qualified person.	Minimize time for calibration and off-line time for transducers.
	Velocity transducer to be calibrated every 30 days.	
	3.0 ENVIRONMENTAL REQUIREMENTS	
3.1 Intrinsic safety.....	Transducer module must meet requirements for intrinsic safety.	30 CFR 27 (9).
3.2 Ambient and/or storage temperatures.	Must be operational between -20° and +40° C within accuracy requirements; must sustain storage temperatures between -40° and +50° C.	Representative U.S. underground coal mine temperatures.
		Dayton T. Brown, Inc. (3).
3.3 Relative humidity.....	Operational at 30 to 100 pct relative humidity.	Do.
3.4 Atmospheric pressure (equivalent).	Operational between 9.7 and 19.7 psi.	Do.
	Low pressure equivalent to 10,000 ft above sea level. High pressure equivalent to 10,000 ft below sea level.	

TABLE 5. - Interim performance specifications for air velocity transducer modules--Continued

Transducer module characteristic	Interim performance specifications	Rationale
3.0 ENVIRONMENTAL REQUIREMENTS--Continued		
3.5 Corrosion.....	Functional after acidified salt spray test (5 pct salt; pH, 3.1 to 3.3 for 120 h).	Dayton T. Brown, Inc. (3).
3.6 Shock.....	Must survive drop test at maximum height (36 in) onto a wooden floor.	Do.
3.7 Electromagnetic interference.	Must survive all conducted and radiated susceptibility tests using National Bureau of Standards spectral densities without transducer degradation.	Do.
3.8 Sand and dust.....	Transducer must be operational at 10 mg/m^3 dust at velocities up to 1,750 ft/min (air cleaner test dust classified from Arizona Road Dust).	30 CFR 27.2 (9).
3.9 Size, shape, and weight.	Minimum weight and size consistent with sufficient ruggedness to endure mine environment.	Physical damage in close quarters possible. To insure system reliability, easy installation of transducer module, and easy maintenance, minimum size and weight are required.
3.10 Design and restrictions.	Must be able to be hung or supported in mine in appropriate places to monitor adequately. Must survive normal mine operations.	Preferred placement of transducer at given site is currently under investigation.
4.0 MAINTENANCE AND OTHER REQUIREMENTS		
4.1 Maintenance: (a) Inspection.....	Performance inspection no more than once per 2 weeks, unless sensor is clearly inoperative (fault condition).	Industry requires low maintenance cost.
	Inspection: Check accuracy at existing air velocity. If out of calibration by >10 pct, recalibrate. Labor and material for inspection >1 pct of unit cost.	See accuracy (item 2.2).
(b) Parts replacement.	<1/2 h by authorized maintenance personnel.	
(c) Parts availability	Spare parts kits must be available at the mine.	
4.2 Sensor life.....	>3 years.	Cost consideration.
4.3 Documentation, installation, and user's manual.	Clearly written and complete installation and user's manual should be provided by manufacturer, including detailed circuit diagrams, and calibration procedures for mine use.	Accuracy requirement and to insure system reliability.

To sum up, the air velocity transducer module must be compatible with the interim monitoring system, e.g., <40 mA (for 20 modules per trunk line) and voltage input of 8 to 18 Vdc. In addition, to insure the intrinsic safety of the monitoring system, system components such as the transducer modules must be intrinsically safe. Response time of the transducer must be less than 120 s to reach a 90-pct final value. Transducer recovery time under loss of power must be short enough (<20 min) to maintain continuous monitoring integrity. Accuracy must be maintained over a monthly schedule. Additionally, the module must survive realistic coal mine environments and meet practical needs such as small physical size and weight.

COMMERCIALLY AVAILABLE AIR VELOCITY TRANSDUCER MODULES

As noted, the components of the first iteration of the ISMMS, other than the ISPS, were to be as nearly as possible off-the-shelf (commercially available) items, including the air velocity transducer modules. Table 6 lists commercially available air velocity transducer modules and characteristics essential for use in the ISMMS. In addition to voltage and current characteristics, range of detection, accuracy, and cost are given. Only a few types of commercially available air velocity transducers are available; a much larger number of air-velocity-measuring instruments (portable or fixed type) exist. Manufacturers of air velocity instruments are potential transducer suppliers.

As can be seen in table 6, the J-Tec VA216B is the only transducer module with sufficiently low current (35 mA) to be considered for the ISMMS; the Thermosystems, Inc., transducer, which is next, requires more than three times higher current.

TABLE 6. - Manufacturers and properties of commercially available air velocity transducers

Manufacturer and model	Input voltage, Vdc	Input current, mA	Output voltage, Vdc	Range, ft/min	Accuracy	Cost (1982)
J-Tec Associates, Inc., VA216B-air draft sensor.	12-21	35 (maximum)	0-5 (output linear).	50-3,000 or 50-1,500 (50-1,000 available on order).	±2 pct of full scale.	$1,475 Replacement draft sensor (not containment or circuit board): $895
Thermosystems, Inc., velocity transducer model 1610.	9	120 at 300 ft/min	0-5 (output linear, 0 to 600 ft/min).	0- 600	±0.5 pct of full scale for 0 to 600 ft/min.	$600
Kurz, model 430, air velocity transducer.	12-15	200	0-5 (nonlinear with velocity).	0- 300 or 0-1,250 or 0-2,500	±2 pct of full scale between -20° and +60° C; ±5 pct at -55° to -20° C and +60° to +125° C.	$495 (replacement probe $250).

The J-Tec VA216B module operates down to velocities of approximately 50 ft/min and requires 35 mA for output of 0 to 5 V (corresponding to 0 to 1,000 ft/min); its performance is independent of high humidity and dust, and it has no moving parts. An earlier model (VA214) of the J-Tec vortex-shedding transducer module was very mineworthy under operating mine conditions (7). The J-Tec VA216B was chosen for use in the first iteration of the ISMMS because of the low current required and because of its expected insensitivity[7] to environmental factors such as temperature, humidity, and dust.

Thorough testing of most table 5 characteristics using J-Tec VA216B air velocity transducer modules is in progress at the Bureau's Safety Research Mine at the Bruceton Research Center and at a cooperating coal mine in Pennsylvania. These results will provide the basis for further refinement of performance specifications for air velocity transducer modules to be used in the ISMMS.

SUMMARY AND CONCLUSIONS

The interim performance specifications for carbon monoxide, methane, and air velocity transducers in the Bureau-developed ISMMS have been prepared and are summarized in the following paragraphs.

CARBON MONOXIDE

The more stringent transducer requirements for ISMMS are as follows:

1. The transducer operating voltage shall range from 8 to 18 Vdc at a current less than 10 mA.

2. The transducer response drift in pure air shall be ±1 ppm CO equivalent per month or less.

3. The overall accuracy characteristic is given by the specifications that over a 1-month period the response inaccuracy, as a combination of bias and precision, shall be less than ±2 ppm CO at a sample concentration of 5 ppm or less and that the inaccuracy shall be less than ±4 ppm CO at a sample concentration of 25 ppm CO.

These requirements are considered necessary for the reliable measurement of CO in an underground coal mine where background levels can range from 5 to 20 ppm CO. These specifications can be best met by the use of a transducer containing an electrochemical carbon monoxide sensor with the sample supplied in a diffusion mode. A test of the operation of several prototype carbon monoxide transducers has been started in a commercial coal mine.

An assessment of these interim standards will be made upon review of the data obtained. Future performance specifications will be used to define the absolute minimum number of parameters that environmental monitoring transducers should meet to fulfill the requirements of a reliable and effective instrinsically safe mine monitoring system.

METHANE

An interim current specification of 80 mA per methane transducer module is given for use with the ISMMS because the desired transducer (40 mA) is not available at present. Two commercially available transducer modules that meet the interim specification (<80 mA) both use the same sensor (Scott). Laboratory and in-mine testing of one of these modules (J-Tec VM101B with the standard sensor) is in progress.

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[7]The VA216B operates on the principle that vortices are formed in air passing around an object. The vortices formed per unit time downwind from a cylinder (the object) are counted. The rate of vortex formation is proportional to air speed. J-Tec uses an ultrasonic method to count the vortices. The frequency is proportional to air speed.

AIR VELOCITY

The J-Tec VA216B meets the interim performance specification of 40 mA current per transducer module. In addition, this module is expected to withstand the mine environment, with little upkeep and without being calibrated more than once a month. The results of testing table 5 characteristics in-mine, coupled with the ongoing research, will provide the basis for further refinement of air velocity transducer performance specifications for use with the ISMMS.

REFERENCES

1. American Society for Testing and Materials. Standard Specifications for Carbon Monoxide in the Atmosphere, D-11 Committee, Sampling and Analysis of Atmospheres. Philadelphia, PA, 1978, 4 pp.

2. Cohen, A. F., and G. H. Schnakenberg, Jr. Applicability and Capabilities of Commercially Available Methane Sensors for Fixed-Point Underground Intrinsically Safe Coal Mine Monitoring. PRC Internal Rept 4420, April 1983, 15 pp.; information available from authors at the Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

3. Dayton T. Brown, Inc. Environmental Test Criteria for the Acceptability of Mine Instrumentation (contract J0100040). BuMines OFR 1-82, 1982, 135 pp; NTIS PB 82-146335.

4. Fisher, T. J., and M. Uhler. Research to Develop an Intrinsically Safe Monitoring System for Coal Mines. Proceedings of the 5th WVU Conference on Coal Mine Electrotechnology, July 30, 31, August 1, 1980 (contract J0100049). BuMines OFR 82-81, 1981, pp. 20-1 to 20-10.

5. Ketler, A. Mine Monitoring Can Aid Production and Cut Costs. Coal Age, v. 86, August 1981, p. 60.

6. Miller, E. J., P. M. Turcic, and J. L. Banfield. Equivalency Tests of Fire Detection Systems for Underground Coal Mines Using Low Level Carbon Monoxide Monitors. Proc. 2d Internat. Mine Ventilation Cong., Reno, NV, Nov. 4-8, 1979. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, 1980, pp. 27-1 to 27-8.

7. National Fire Protection Association. Intrinsically Safe Apparatus for Use in Division 1 Hazardous Locations. NFPA Bull. 493, 1978, 55 pp.

8. Scott, L. W. Remote Monitoring of Air Quality in Underground Mines. BuMines RI 8253, 1977, p. 3.

9. U.S. Code of Federal Regulations. Title 30--Mineral Resources; Chapter 1--Mine Safety and Health Administration, Department of Labor; Subchapters A-P, Parts 0 to 199. July 1, 1982, 688 pp.

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